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PROCEEDINGS

Electroplating and Epoxy Repair Methods for Corroded 70/30 CuNi and Alloy 400 Seawater System Components.

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ABSTRACT

70/30 CuNi and alloy 400 components used for Navy seawater immersion applications suffer a variety of corrosion problems including pitting, crevice corrosion, and galvanic corrosion. An effective method for repair of corroded components would result in significant cost savings by allowing refurbishment rather than replacement of damaged components. Electroplating and epoxy repair methods were tested to determine their effectiveness for repair of these alloys. Materials and techniques were selected based on availability and current usage at Navy shipyards. Corrosion tests were developed which represented typical corrosion environments for 70/30 CuNi and alloy 400 components. Pipe specimens that contained both control and repair areas were tested for approximately 1 year in static seawater. Based on the test results, recommendations were made for repair of corroded 70/30 CuNi and alloy 400 components using electroplating and epoxy repair techniques.

INTRODUCTION

70/30 CuNi and alloy 400 components used for Navy seawater immersion applications are susceptible to a variety of corrosion mechanisms including pitting, crevice corrosion, and galvanic corrosion. Problems resulting from corrosion can adversely affect overall performance of a system constructed with these alloys and can result in

high repair or replacement costs. Effective, long-lasting repair methods would result in significant cost-savings by eliminating the need for replacement parts and reducing the need for reapplication of an inadequate repair method.

Navy shipyards presently use electroplating or epoxy coatings to repair corroded surfaces on 70/30 CuNi and alloy 400 ship seawater system components. These systems include submarine shaft seals, seawater pumps, seawater piping and valves, and logistics escape trunks to name a few. Copper or a combination of copper and nickel are used for electroplate repair. Repairs are normally accomplished in accordance with MIL-STD-2197 (SH) (Brush Electroplating on Marine Machinery) [1]. Repairs of corroded components are also made with a variety of epoxy filler materials. However, the corrosion performance of electroplated or epoxy repaired surfaces has not been tracked in the fleet in a systematic manner. As a result, the service performance lifetime of the various types of repair (and on different depths of attack) is unknown. There is no data base to permit selection of one repair method as the most suitable one for a particular repair application. Since no performance data exists, there is no standard repair method and each shipyard or intermediate maintenance activity (IMA) uses whatever method that has appeared to be "successful" during previous repairs. The identification of superior materials and methods to repair corrosion and minor surface defects would have widespread application in the submarine and surface fleet.

Corrosion tests were developed to evaluate electroplate and epoxy repair methods for corroded 70/30 CuNi and alloy 400 components. Test conditions were selected to simulate a typical corrosion environment for these alloys. Specimens were tested with control areas without repair and areas which had been repaired with electroplate and epoxy techniques. At the completion of testing, effectiveness of the repairs versus the control areas was evaluated. The objective of this report is to present the results of the electroplating and epoxy repair tests and provide recommendations to develop standard repair procedures.

MATERIALS AND SPECIMEN PREPARATION

To simulate repair of O-ring sealing surfaces, a test matrix was designed to comparatively evaluate seawater corrosion performance of epoxy compounds and electroplating on 70/30 CuNi and alloy 400 pipe specimens, Table 1.

Table 1. Test matrix for electroplating and epoxy repair specimens.

Substrate Material	Repair Method	Repair Material	Depth of Repair, inches			Specimens/ Substrate*
70/30 CuNi Mil-T-16240K 70/30 CuNi or Alloy 400 ASTM B 127-85 UNS N04400	Epoxy	Phillybond Blue 6A		0.015"	0.025"	8
		Belzona Molecular Ceramic Metal		0.015"	0.025"	8
		Belzona Molecular Super Metal		0.015"	0.025"	8
		Devcon Ceramic Compound Type I		0.015"	0.025"	8
		Devcon Underwater (UW)		0.015"	0.025"	8
	Electroplating	Copper 2050	0.008"	0.015"		8
		Copper 2050 with Nickel 2080 cap	0.006" Cu 0.002" Ni	0.013" Cu 0.002" Ni		8
		Copper 2050 with Aeronikl 250 cap	0.006" Cu 0.002" Ni	0.013" Cu 0.002" Ni		8
Alloy 400	Electroplating	Aeronikl 250	0.008"			4
					Total Specimens =	68

* 4 specimens per depth of repair

Two types (type I and II) of test specimens were used to represent repaired surfaces, Figures 1 and 2, respectively. Type I (one wide groove) had the repair treatment applied to all of the area adjacent to and under the O-ring sealing surface (Figure 1), while the type II (two narrow grooves) had the repair treatment applied only adjacent to each side of the O-ring sealing surface (Figure 2). Crevice corrosion of 70/30 CuNi and alloy 400 typically occurs adjacent to O-ring sealing surfaces. Each pipe specimen had five O-ring repair sites and one O-ring control site. The pipe/O-ring test created severe crevice situation which permitted a relative ranking of repair techniques.

The electroplating materials tested included Sifco Solutions Copper 2050[*] (Cu2050), Copper 2050 with a Nickel 2080[*] (Ni2080) cap, Copper 2050 with an AeroNikl 250[*] (Ni7280) cap, and AeroNikl 250; while the epoxies tested included Phillybond Blue 6A[+] (Phillybond), Belzona Molecular Ceramic Metal R[#] (Belzona Ceramic), Belzona Molecular Super Metal[#] (Belzona Super Metal), Devcon Ceramic Compound type I[&] (Devcon Ceramic), and Devcon Underwater[&].

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& Trademark of ITW Devcon, Inc.

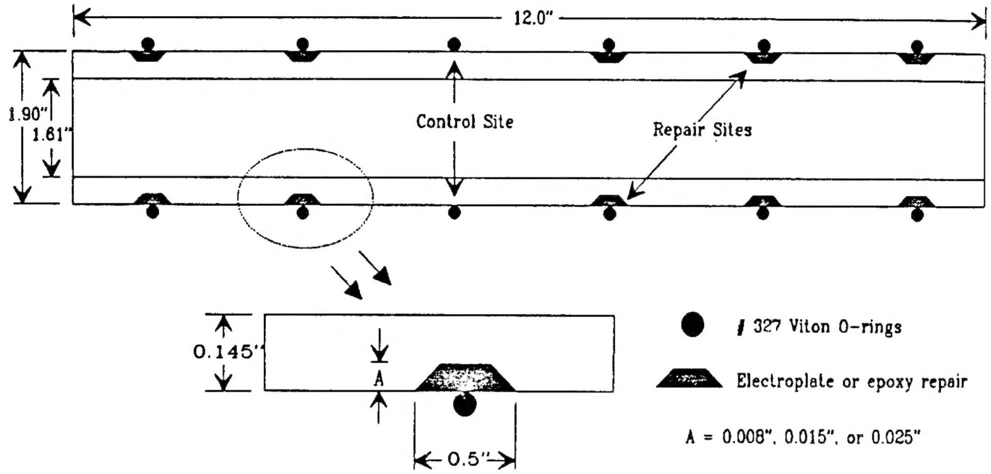

Figure 1. Electroplate/epoxy type I specimen (all dimensions in inches (")).

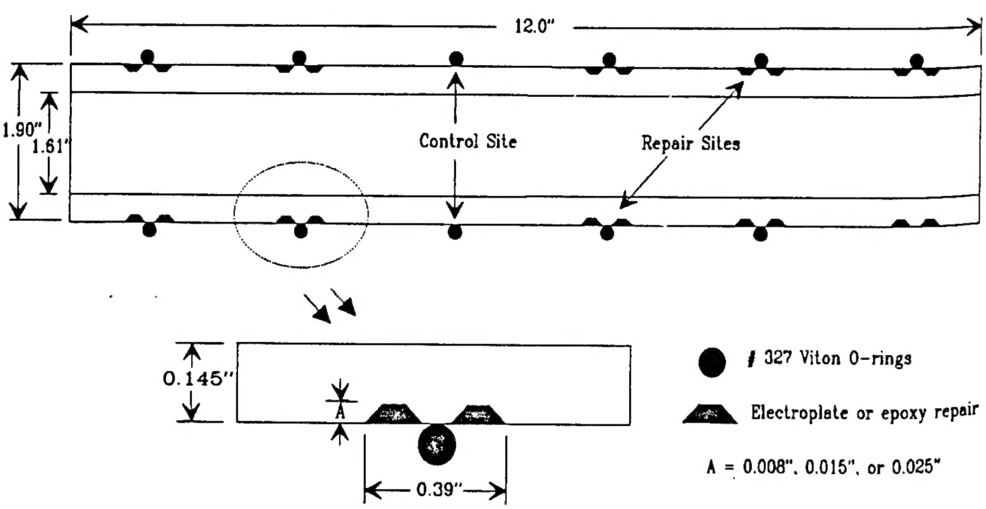

Figure 2. Electroplate/epoxy type II specimen (all dimensions in inches (")).

For a given repair treatment, there were four test conditions per substrate material: type I (two depths of repair) and type II (two depths of repair). The electroplating solutions were applied to repair depths of 0.008 and 0.015 in. while the epoxies were applied to depths of 0.015 and 0.025 in.

CDNSWC tasked both Puget Sound Naval Shipyard (PSNS) and Pearl Harbor Naval Shipyard (PHNS) to apply the epoxy compounds and electroplating solutions. Each shipyard was requested to apply the same repair treatments and to document their application procedures.

AS-RECEIVED CONDITION OF REPAIRS

Before the tests were initiated, the condition of the repaired areas on the pipe specimens and the repair application procedures were examined. Significantly different procedures were followed by each shipyard which varied the initial condition of the repairs. In the remainder of this report, the specimens from Puget Sound will be designated as PS while the specimens from Pearl Harbor will be PH.

The final surface condition was found to vary between the two shipyards. All of the PH specimens were machined to a smooth surface finish after the repairs were made; whereas the PS specimens were delivered in the as-applied condition. Final machining provided a smoother surface finish than the as-applied condition but also reduced the nickel cap thickness of the electroplate repairs.

A major difference was found between the initial surface preparation of the epoxy repair specimens. Repair areas of the PS specimens were sandblasted before applying the epoxies, whereas PH specimens were not. Sandblasting significantly improves the adhesion of epoxies compared to epoxies applied to a smooth, machined surface [2].

TEST CONDITIONS

A total of 132 electroplate and epoxy repair specimens, or 792 O-ring sites, were immersed in natural seawater for 11 months (Dec 18, 1990 to Nov 18, 1991) at the Naval Research Laboratory (Key West, FL). The pipe specimens were placed in PVC racks and immersed in a seawater trough parallel to the seawater flow. Each specimen rested on its outer two O-rings to avoid creating additional crevices. Seawater was continually refreshed at a trickle flow rate. The average seawater temperature during the test exposure was 27.7°C while the average salinity was 37.1 ppt and average pH 8.1.

After 11 months in seawater, the specimens were removed and examined for corrosion of the substrate and coating performance. Depth of attack measurements were taken under and adjacent to the O-ring at the control site, adjacent to the epoxy coatings, and under and adjacent to the O-ring on the electroplate coatings. Photographs were taken to document the inspection.

RESULTS AND DISCUSSION

After removal and cleaning of the test specimens, relative performance of both electroplate and epoxy repairs were evaluated. Each specimen had 5 repair sites; the performance of the repair method on each specimen was rated based on how many sites were completely intact (0-5 with 5 being the best rating since all sites would have passed).

The electroplate repairs were considered to have failed when any corrosion damage occurred to the electroplate. Results of this evaluation are provided in Figure 3.

The epoxy coatings were rated as having passed or failed based on the following conditions for failure: blistering, chipping, spalling, swelling, or movement of the coating. The coatings were also considered failures if they could be twisted off by hand. The results of this inspection are provided in Figure 4.

A significant difference in performance of the repairs was seen as a result of variations in procedure between the two shipyards. The nickel-capped electroplate specimens which were left in the as-electroplated condition remained intact more often than the specimens which had been final machined. Also, the epoxy coatings which had been sandblased consistently provided better adhesion and showed less instances of failure than the specimens which had no sandblasting. A discussion of the results for each repair type follows.

Percentage of Sites

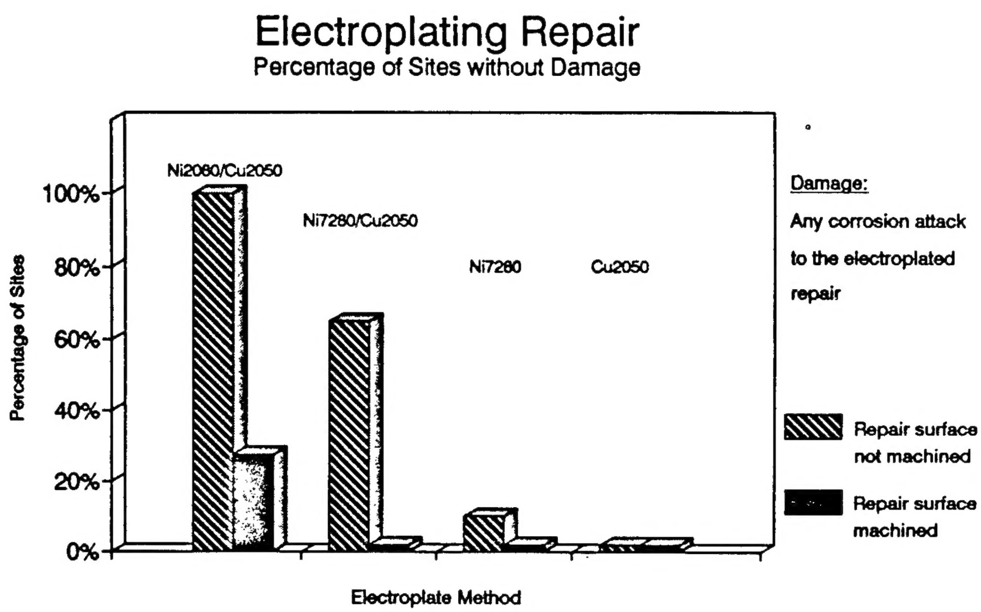

Figure 3: Results of electroplate repair corrosion tests.

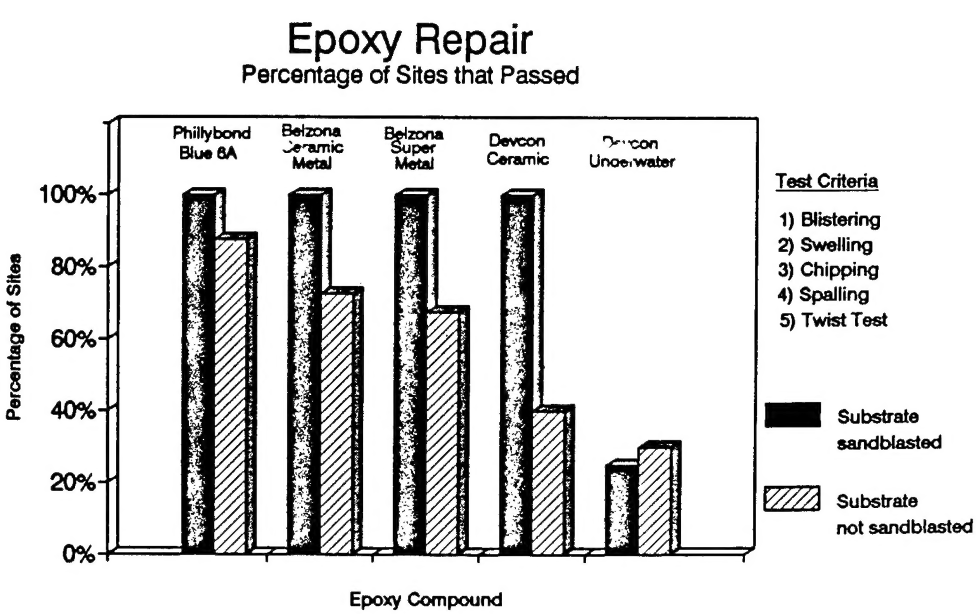

Figure 4. Results of epoxy repair corrosion tests.

ELECTROPLATE REPAIR

Cu2050 performed poorly as an O-ring sealing surface repair on both 70/30 CuNi and alloy 400. Cu2050 was found to be less noble than either substrate material and subsequently the O-ring seal area was damaged by galvanic corrosion, Figure 5. The corrosion was most severe adjacent to the O-ring which suggests that crevice corrosion was also a factor. Cu2050 was able to suppress some corrosion of the substrate, including reduced attack at the control sites. However, once the copper was sufficiently depleted, crevice corrosion of the substrate initiated. Electroplating with copper over a large surface area may suppress corrosion for a limited time, but the electroplate will galvanically corrode away leaving the original damaged area. It is recommended that Cu2050 not be used as a repair method on 70/30 CuNi or alloy 400.

Ni7280 without a copper preplate also performed poorly on the three alloy 400 specimens tested. The electroplate was subject to crevice attack directly under the O-ring and also showed some evidence of galvanic corrosion. Electroplate repair with Ni7280 was also shown to perform poorly on metal-to-metal crevices of alloy 400 in previous CDNSWC testing. Based on the limited data collected in this test and the data from previous tests, Ni7280 without a preplate is not recommended for repair of alloy 400 surfaces.

Ni2080 with a Cu2050 preplate performed best of the electroplated repair specimens, Figure 6. The only damage on the electroplating repairs was seen on the finished PH specimens. Machining of these specimens reduced the thickness of the nickel cap to a level insufficient to blanket the entire copper preplate. By adjusting the procedure to specify a minimum cap thickness, this problem should be avoidable. In addition, Ni2080 without a preplate applied to alloy 400 has previously been recommended for repair of corrosion in alloy 400 and 70/30 CuNi metal-to-metal crevices. Omitting the copper preplate guarantees that the electroplate will not fail from exposure of copper. However, a Cu2050 preplate is sometimes used since it is easier to deposit and thicker layers can be applied before additional surface preparation (reactivation) is required. The maximum one layer buildup before reactivation is 0.007 in. for Ni2080 and 0.015 in. for Cu2050 [3]. If feasible, the Ni2080 should be used without a preplate. However, if a preplate is necessary, a minimum Ni2080 cap thickness of 0.004 in. should be maintained over the entire preplate after finishing the surface is completed. This is to ensure that no copper is exposed at the surface of the repair. It is recommended that a fleet evaluation be performed of Ni2080 electroplate repair of either alloy 400 or 70/30 CuNi components.

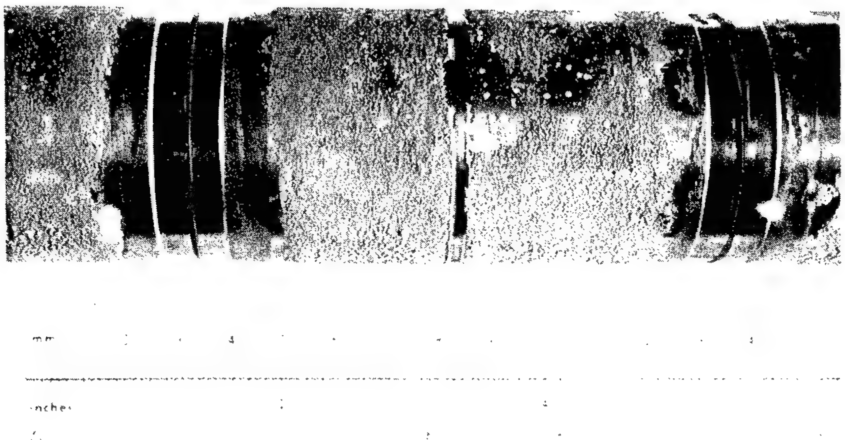

Figure 5. Control site (middle) and corroded electroplated sites on alloy 400 specimen electroplated with Cu2050.

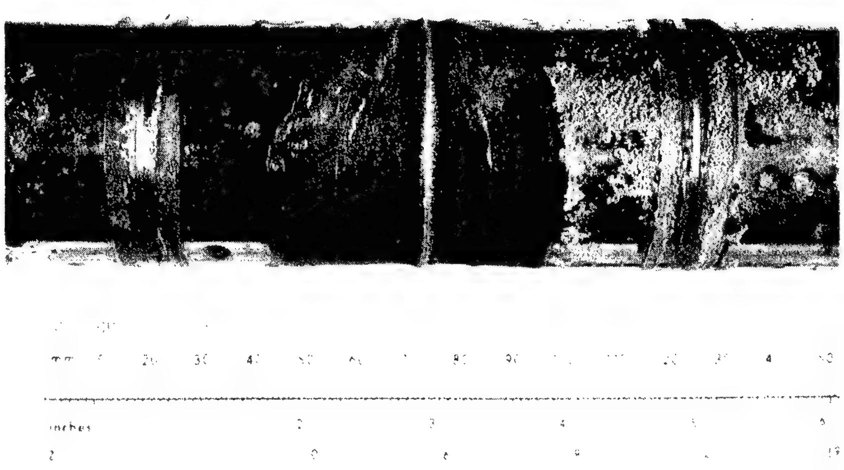

Figure 6. Control site (middle) and electroplated sites on alloy 400 specimen electroplated with Ni2080 (Cu2050 preplate).

Ni7280 capped over Cu2050 was less successful than the Ni2080 capped specimens. The Ni7280 was susceptible to crevice corrosion directly under the O-ring and also showed signs of galvanic attack. Once exposed, the Cu2050 galvanically corroded under corroded areas of the Ni7280 causing failure of the entire repair. The machined PH specimens showed higher rates of failure for reasons similar to the Ni2080 caps (reductions in cap thickness, attack of the copper preplate). Based on the results of this test, Ni7280 should not be used as a repair for shaft seal O-ring sealing surfaces.

For some of the nickel capped specimens, corrosion of the median on the type II specimens also caused exposure of the copper preplates. This occurs because corrosion directly adjacent to O-rings on 70/30 CuNi and alloy 400 can undercut the nickel cap. To prevent exposure of copper, the nickel cap should be applied to a wider area than the preplate.

EPOXY REPAIR

The PS specimens which had the grooves sandblasted prior to application of the epoxy showed superior resistance to failure. When sandblasted, 4 of the 5 epoxies had no failures on type I specimens. A representative specimen showing the good performance of epoxy is shown in Figure 7. Surface preparation is extremely important when applying mechanically bonded materials [2]. The roughened surface produced from sandblasting significantly increases the bond strength and therefore provides a longer lasting coating. Wherever feasible, it is recommended that sandblasting be done on all surfaces which are to be repaired by epoxy. Methods to sandblast limited access areas (eg., narrow width O-ring grooves) and to sandblast small areas on components aboard ship (without grit dust in the air) should be developed.

Most failures of epoxy coatings were seen on unsandblasted and type II specimens. These failures were caused by poor adhesion of the coatings allowing seawater to leak under the coatings. The Devcon Underwater had the worst performance of any of the epoxy repairs, Figure 8. Seawater leakage under this coating caused blistering and spalling of the coating. Of the 80 sites that were repaired with Devcon Underwater, 58 failed. Sandblasting of the grooved surface did not improve this coating's resistance to failure.

The other four epoxies evaluated: Phillybond, Belzona Ceramic, Belzona Super Metal, and Devcon Ceramic, all showed similar modes of failure. First, adhesion problems would permit water penetration, to

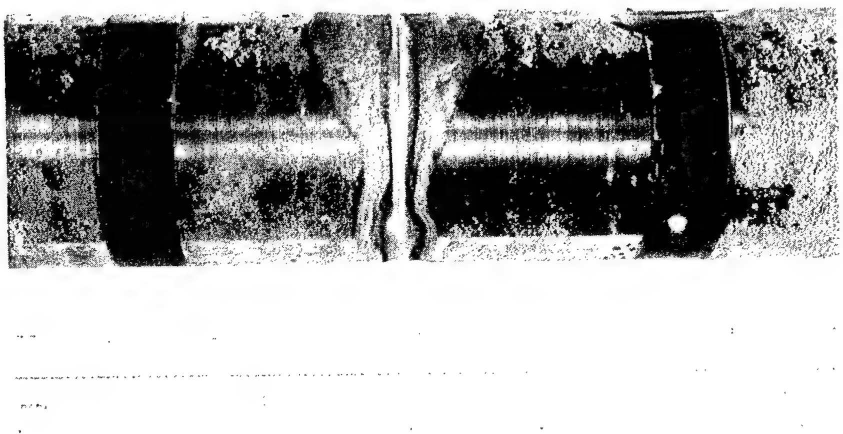

Figure 7. Control site (middle) and epoxy repaired sites on alloy 400 specimen repaired with Phillybond Blue 6A.

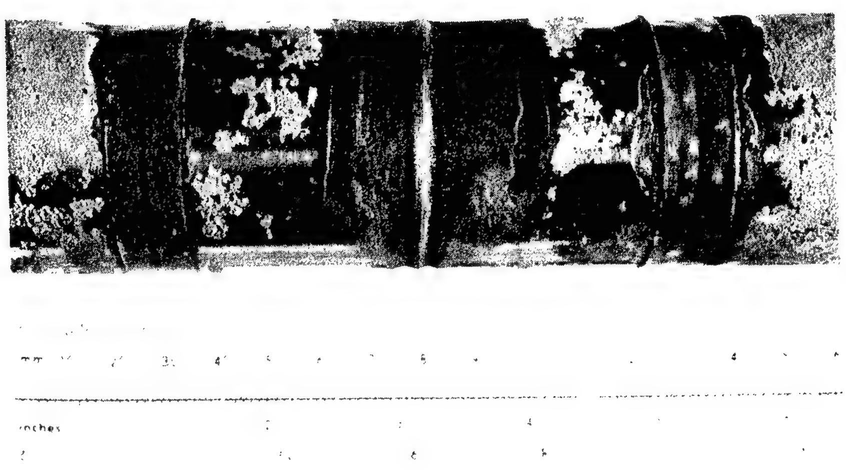

Figure 8. Control site (middle) and blistered epoxy repair sites on alloy 400 specimen repaired with Devcon Underwater.

some extent, under the coating. This has been confirmed by the presence of stains on the substrate underneath coatings which have been manually removed. A crevice situation would then develop under the coating causing corrosion at the edge of the repair. For type II repairs, water leakage under the coatings was also a result of crevice attack of the median undercutting the epoxy edges. Corrosion products apparent at the edges of epoxy confirm the median corrosion. Both the water under the coating and the undercutting of the substrate from corrosion of the type II median reduced the adhesion strength of the epoxy. This poor adhesion eventually resulted in failure. Excluding Devcon Underwater, about one third of the unsandblasted PH repairs failed. Phillybond Blue 6A had the least amount of failures (5) suggesting this epoxy had the best adhesive bond strength. Phillybond was followed in order by Belzona Molecular Ceramic Metal (11), Belzona Molecular Super Metal (13), and Devcon Ceramic Compound (24).

The surface condition of the epoxy repairs can be qualitatively evaluated based on observations of the finished PH specimens. These specimens were compared based on surface smoothness and voids. The Phillybond appeared to provide the smoothest finish of the epoxies evaluated. Belzona Ceramic and Belzona Super Metal both showed slightly rougher surfaces than Phillybond. The surface condition of Devcon Ceramic could not be accurately determined because PH specimens did not have the epoxy topcoat applied. The Devcon Ceramic undercoat was fairly smooth, but contained numerous voids. The topcoat may help to reduce the number of voids on the epoxy surface. The Phillybond and the Belzona Ceramic both had few voids of very small dimensions. The Belzona Super Metal contained only a few voids, but they tended to be larger on average than for the other epoxies.

REPAIR METHOD SELECTION

Factors influencing which method is most suitable for a specific repair include the resistance to failure, the effect of a failure on subsequent system performance, the cost of the repair, and the time required for the repair. Epoxy repairs and electroplated repairs both offer good resistance to failure if proper application procedure is followed.

Areas with less than 0.007 in. of attack should be electroplated with Ni2080 whenever feasible. Although immediate repair of damage of this extent may not be required, it is recommended whenever time permits. Early repair of damage will reduce or even eliminate the need to make repairs in the future. For areas with deeper attack than 0 .007 in.,

Cu2050 may be applied as a preplate under a Ni2080 cap as long as the cap has a minimum thickness of 0.004 in. Care must be taken to ensure that this minimum thickness is maintained after the surface is machined. The Ni2080 cap must also be applied to an area wider than the area plated with Cu2050 to ensure that the edges of the repair are properly covered. It is essential that no copper be exposed at the surface or edge of the repair.

A proposed procedure when using a copper preplate, shown in Figure 9, would be to first fill the damaged area with Cu2050 to within 0.004 in. of the substrate. Grind down an area a minimum of 0.063 in. wider than the Cu2050 to a minimum depth of 0.004 in. Finally, overfill this area with Ni2080 and finish to a smooth surface even with the substrate.

If electroplating repair is not feasible, epoxy repair can be considered. Epoxy repairs may be more appropriate for areas with depth of attack greater than 0.020 in. since electroplate deposit thicknesses may be difficult to achieve due to cost and/or time limitations. Epoxy repairs should have the corroded area carefully cleaned and sandblasted prior to coating application. It is recommended that Phillybond Blue 6A be used over a sandblasted surface although Belzona Molecular Ceramic Metal R, Belzona Molecular Super Metal, and Devcon Ceramic Compound (type I) may also provide good performance with this surface preparation. Since epoxies were seen to be susceptible to seawater penetration at the edges, they should be applied over as wide an area as possible to achieve the best adhesion. Epoxies must be used with caution since crevice corrosion may occur at the coating edges.

The effect of expected service environment on repair performance, and the effect of possible repair failure on subsequent component performance may dictate a particular repair selection. For instance, if an epoxy coating applied to a boldly exposed surface fails, it may completely disbond from the substrate. This failure may be catastrophic and fragments of the coating may become dislodged. On the other hand, electroplated repairs tend to fail more gradually as corrosion attacks the surface or the underlying preplate. On boldly exposed surfaces or sliding seal surfaces, and for shallow repairs, electroplate repairs would be suggested. However, epoxy coatings may be ideal for deep attack in between captured surfaces, on flange faces or pump casing halves, for instance.

The cost of a certain repair consists of the material costs and labor. The cost of the epoxy materials and the electroplating solutions is

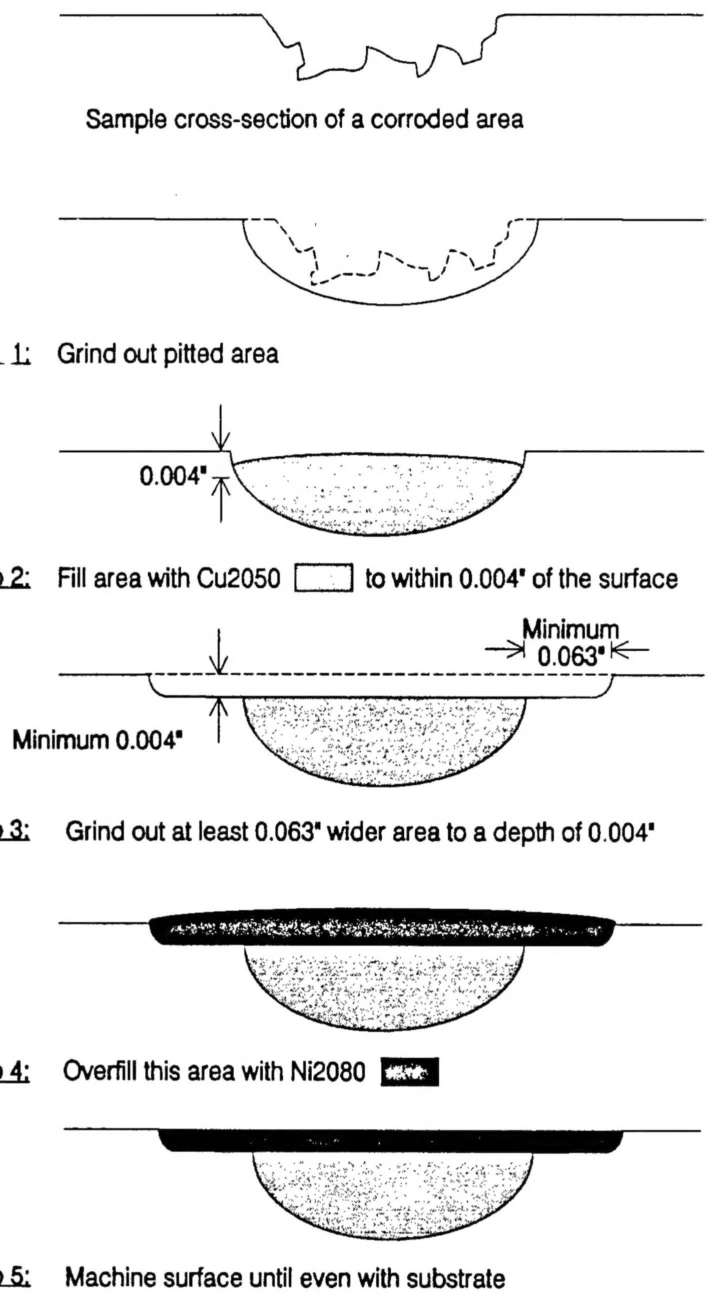

Figure 9. Recommended procedure for electroplating Ni2080 with Cu2050 preplate.

fairly insignificant compared to the labor costs involved. Electroplating generally requires more labor time than epoxy applications, especially when multiple layers of electroplate are required. Therefore, electroplating may be more feasible for shallower grooves where two or less layers of electroplate is required. However, the effect of possible failure on service performance will probably be the determinant factor in repair method selection.

In addition to service environment and labor costs, restricted availability for repair also contributes to selection of repair method. For example, during time-restricted component availabilities, epoxy may be easier to apply than electroplating, especially for deeper repairs.

When electroplating, it is recommended that MIL STD 2197 (SH), "Brush Electroplating on Marine Machinery" [1] be followed supplemented by the instruction manual for the electroplate solutions. The Sifco Selective Plating Dalic Process Instruction Manual [3] was utilized by both shipyards. It is also recommended that when a copper preplate is being used, a minimum cap thickness of 0.004 in. be maintained over a minimum 0.063 in. wider area than the preplate as previously detailed (Figure 9).

Proper surface preparation was found to be the most important criteria when applying epoxies. Therefore, it is recommended that sandblasting be performed on all surfaces repaired with epoxy. The details on applying each epoxy type; e.g. temperature, mixing, curing time, etc., were unique to the instructions supplied by the manufacturer of each epoxy and it is recommended that these specific instructions be followed for each compound.

SUMMARY AND RECOMMENDATIONS

Corrosion tests were conducted to evaluate the relative performance of electroplate and epoxy repair methods presently used by Navy Shipyards to refurbish areas of corrosion on 70/30 CuNi and alloy 400 components. In approximately one year seawater immersion tests, both electroplating and epoxy repairs were found to offer protection from corrosion in the repaired area. The performance of the several repair methods was similar on both 70/30 CuNi and alloy 400. Test results indicate electroplating can provide excellent service when used as a repair in the shaft seals area. Epoxy repairs should probably be limited to captured surfaces, or large areas of deep repair to obviate problems with disbondment and subsequent dislodgement of chunks of epoxy into operating systems.

Of the electroplating materials evaluated, Ni2080 had the best

performance and is recommended over Ni7280 or Cu2050. Cu2050 may be used to fill under the Ni2080, provided a minimum cap thickness of 0.004 in. should be maintained over a minimum 0.063 in. wider area than the preplate.

Of the epoxies, Phillybond Blue 6A had the best performance on unsandblasted specimens and the smoothest surface finish. If the substrate surface was sandblasted before applying epoxy, four epoxies had good performance: Phillybond Blue 6A, Belzona Molecular Super Metal, Belzona Molecular Ceramic Metal R, and Devcon Ceramic Compound (type I). Devcon Underwater performed poorly in this test and is not recommended. Epoxy repairs should be applied on a sandblasted or equivalently prepared substrate surface.

REFERENCES

1. MIL-STD-2197 (SH), "Military Standard: Brush Electroplating on Marine Machinery," 28 March 1989, Superseding NAVSEA 0900-LP-038-6010, September 1972.

2. Surface Preparation: The State of the Art, Proceedings of the SSPC Annual Symposium, May 1985.

3. SIFCO Selective Plating, Dalic Process Instruction Manual, 4th Edition SIFCO Industries, Inc., (1985).